Amendments to the Specification:

Before "BACKGROUND OF THE INVENTION," please insert:

"This application is a National Phase of PCT/US05/004567, filed February 14, 2005, which claims priority to U.S. Provisional Application No. 60/545,139, filed February 18, 2004, which is hereby incorporated by reference."

[0005] Pressure-assisted sintering using commercial silver metal paste to attach electronic components was discussed in Zhang et al., "Pressure-Assisted Low-Temperature Sintering of Silver Paste as an Alternative Die-Attach Solution to Solder Reflow," IEEE Transactions on Electronics Packaging Manufacturing, vol. 25, no. 4, October, 2002 (pp 279-283); and Zhang et al., "Pressure-Assisted Low Temperature Sintering of Silver Paste as an Alternative Die-Attach Solution to Reflow," *The ~~Fifty~~ Fifth International Component Failure Analysis in Electronics Manufacturing* (HDP 2002). The metal powder in commercial silver metal paste typically has a particle size in the micrometer range. Because of the large particle size, a high sintering temperature is required (600°C and up) under normal firing conditions. At reduced firing temperature, a large pressure is applied on the assembly to assist the sintering process. However, the application of pressure can be undesirable because of increased difficulty in manufacturing with a corresponding increase in the production cost. Applying pressure also increases the likelihood of damage to the device during processing.

[0035] Nanoscale silver paste versus micrometer-size silver paste Silver compares favorably with other known interconnect materials such as solder and silver-filled conductive epoxy.

Eutectic Pb-Sn solder is used in the vast majority of interconnections although lead-free alternatives are gaining ground. For higher-temperature applications such as bonding of light emitting diodes (LED) and semiconductor lasers, the eutectic AuSn is often recommended because they can go to higher temperatures than Pb-based or Sn-based solders. However, it is a far more expensive solution. Silver-filled conductive epoxies are currently used for silicon device interconnect applications. For example, conductive epoxy is used in International Rectifier's <u>DirecFTE</u> secure the silicon dice to a copper cavity. The properties of these materials are listed in Table 1 and some are also shown in Figures 4a-c.

[0037] With the addition of the proper types of dispersant, binder, and solvent, the onset of sintering can be delayed until such time that the preferred firing temperature is reached ([[-]]280 to 300°C) to enable very fast densification rates and attain not only high density, but also good adhesion onto the device and substrate. Therefore, in addition to the reduction in particle size, an important ingredient to the usability of the paste is the selection of the dispersant and binder system that can be volatilized and burned off just below the sintering temperature. If the binder system leaves the paste too early, the silver nanoparticles will start sintering at a lower temperature, and consequently with reduced kinetics, the activation of a non-densifying mechanism, e.g. surface diffusion, occurs resulting in a microstructure that is difficult to densify even at the higher targeted sintering temperature. If the binder system components burn off at a temperature higher than the desired firing temperature, the silver particles will not sinter properly because the polymer components will prevent the widespread contact between particles. A top size of 500 nm (a size that is not traditionally in the size range considered as "nanoscale") is a

practical limit for this technique because the sintering temperature will rise accordingly, which could go beyond the desired range and, of course, will no longer be suitable as a solder drop-in replacement. Most of the experimental work performed to date and reported herein, other than commercial Ag paste, has been performed on powder 100 nm or smaller.

[0041] Comparison of process for different types of interconnect materials. Some high-temperature-melting solders are currently used for high-temperature semiconductor device interconnect applications. For example, Au-Sn eutectic solder can be reflowed at 310-330°C and used at a temperature below its melting point 280°C. The major differences between the solder reflow and the nanoscale silver paste sintering of the present invention include:

1) Solder is processed by heating the alloy above its melting temperature to form the bond. The alloy undergoes melting and solidification after the completion of the procedure known as solder reflow. The requirement to melt the alloy means that only those with low melting points are suitable. This restriction also limits the maximum operating temperature of the joint to below the melting point.

2. Conductive epoxy is hardened by curing above room temperature to induce the epoxy to undergo a setting reaction. While the process temperature is low and no melting is involved, the maximum working temperature is limited by the decomposition temperature of the epoxy component, which is in the range of the curing temperature.

3) Attachment/interconnection by nano-silver paste, according to the present invention, is achieved through a sintering process wherein the silver nanoparticles undergo consolidation through diffusion processes rather than by melting. By doing so, high processing temperature is

avoided. On the other hand, because the melting point of bulk silver is much higher than the sintering temperature of nano-silver particles, the interconnections can be operated at temperatures higher than the processing temperature. In sum, the nanopowder sintering technique of this invention is a low-temperature bonding solution for high-temperature applications. The sintering temperature can be reduced significantly by making the particle size of the powder smaller. As shown above and as is discussed in comparative example 3, the sintering temperature of silver can be drastically reduced if micrometer-size particles are replaced by nanoscale particles. It is then possible to lower the sintering temperature to that of the reflow temperature of many solder alloys.

[0042] Prior art on the use of silver paste containing micrometer sized silver. Currently available commercial silver/silver alloy pastes contain micrometer-size silver (silver particles larger than 500 nm in size and typically on the order of in size). Typically, these pastes have to be fired to a high temperature approaching the melting point of the alloy to achieve high density. For example, the recommended firing profile of silver paste is to heat it to around 900°C (although it is possible to obtain reasonably high density for mechanical strength at lower temperatures, e.g. 700°C). They are most often used to form conductive <u>traces</u> (package substrates) and electrodes (capacitors) for various electronics applications. They are not typically used for forming interconnects between devices and substrates, as is proposed in the present application.

[0043] There are numerous vendors for these products such as DuPont, Heraeus, and Ferro. Silver paste has also been considered as a die-attach and interconnect material. To make it work, an external pressure is applied to the assembly (about 40 MPa) to lower the sintering temperature to or lower than 300°C (see, for example, H. Schwarzbauer, "Method of securing electronic components to a substrate," U.S. Patent 4,810, 672; H. Schwarzbauer and R. Kuhnert, "Novel large Area jointing technique for improved power device performance," IEEE Trans. Ind. Appl. 27 : 93- 95,1991; and Z. Zhang and G. Q. Lu, "Pressure-assisted low-temperature sintering of silver paste as an alternative die-attach solution to solder reflow," IEEE Trans. Electron. Pack. 25 (4): 279-283,2002), which is basically the maximum temperature a semiconductor device can be exposed to without destroying it. However, high applied pressure is not the norm in the packaging industry and could pose serious complications to the attachment/interconnection process, which in turn could lead to more failures (e. g., cracked die) and higher manufacturing costs. It may require major modifications to existing production lines, thus it may not be considered as a drop-in replacement for solder. The higher cost alone may discourage industry from adopting it.

[0044] Results for pressure-assisted sintering of commercially available silver paste (micrometer sized) are summarized in Table 2. A reasonably high density (80%) can be attained only if the external pressure on the joint is dramatically increased. This is also accompanied by substantial 142 increases on some key parameter values of the sintered Ag joint such as electrical conductivity, thermal conductivity and shear strength. In contrast, with the nanoscale silver paste of this invention (less than 500 nm and more preferably less than 100 nm in size), it is not

necessary to apply such a high pressure to induce sintering and bonding, thus making it a potential drop-in replacement for solder and/or epoxy for die attachment and electrical interconnection. In practice, the pressure used before the silver sintering with the silver paste of the present invention may be used only for better initial interface contacts, and it is recommended that this pressure should not exceed 0.1 to 0.2 MPa, depending on paste viscosity, so that the silver paste does not get squeezed out (this procedure is very common on solder reflow die-attaching).